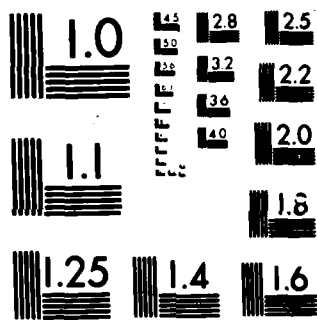END

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THESIS

ANALYZING THE COST EFFECTIVENESS
OF USING FLIGHT SIMULATORS IN THE
ISRAELI AIR FORCE

by

Uzzi Rozen

December 1985

Thesis Advisor: Roger Evered

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This thesis describes a way to analyze the cost effectiveness of the present mix of flight simulators and flying hours in the training process of the I.A.F. air crews. The jet fighters, helicopters, and transportation communities are used as examples to demonstrate the implementation of the analysis. These examples give the reader a general picture of the cost effectiveness of using flight simulators in the I.A.F.

Analyzing the Cost Effectiveness
of Using Flight Simulators in the
Israeli Air Force

by

Uzzi Rozen
Lieutenant Colonel, Israeli Air Force

Submitted in partial fulfillment of the
requirement for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

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December 1985

Author: _____
Uzzi Rozen

Approved by: _____
R. Evered, Thesis Advisor

_____
N. Hodoni,ai, Thesis

_____
W. R. Greer
Chairman, Department of Administrative Sciences

_____
Kneale T. Marshall
Dean of Information and Policy Sciences

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ABSTRACT

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give the reader a general picture of the cost effectiveness
of using flight simulators in the I.A.F.

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I. INTRODUCTION

A. PURPOSE

The important role of air superiority in the defense of
Israel has always been in conflict with the requirements of
a wealthy and healthy economy as a foundation to a democratic
independent state. About a decade ago, the increasing cost
of training flying hours, and the increasing rate of required
flying training hours to attain air superiority reached the
point at which economic resources were insufficient. The
"blanket" is too short; no matter how we use it, a part of our
body will be exposed to the cold. This situation, and the
shrinking airspace as a result of the peace treaty with Egypt
in 1979, were the main causes for accelerating the use of flight
simulators in the Israeli Air Force. During the last decade
a few advanced simulators were acquired and were used for some
of the training tasks. For other training tasks the pilots
use commercial and military simulators outside the country.
The attitude toward the simulator has changed since the days
in which simulators were used for procedures and instrument
flying training only, and the feeling among most of the fliers
and command levels is that the simulator is paying back what
had been invested in it.

No comprehensive cost-effective analysis for selecting the
proper mix of the flying and simulator training hours in the
I.A.F. has been done. The purpose of this study is to provide

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an analytic tool to perform such an analysis. Two questions
initiated the study:

   (a) Is the existing mix of flying and simulator training
       hours cost effective?

   (b) What is the potential cost effectiveness mix of flying
       and simulator training hours?

B. STUDY METHODOLOGY

   The methodology that was chosen for this study is the one
that is common to most of the cost effectiveness analysis.
Figure I - 1 describes the study methodology.

```
┌─────────────────────────┐
│   Cost Effectiveness    │
│       Criterion         │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐        ┌─────────────────────────┐
│  Training Effectiveness │◄───────│   I.A.F Pilots and      │
└─────────────────────────┘        │     Headquarters        │
            │                       └─────────────────────────┘
            ▼
┌─────────────────────────┐        ┌─────────────────────────┐
│     Training Cost       │◄───────│   I.A.F. Headquarters   │
└─────────────────────────┘        └─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│   Training Cost         │                ┌─────────────────────────┐
│   Effectiveness         │──────────────► │      3 groups           │
└─────────────────────────┘                │   in the I.A.F.:        │
            │                               │  Jets, Helicopters      │
            ▼                               │    Transports           │
┌─────────────────────────┐                └─────────────────────────┘
│   Cost Effective Mix    │──────────────►
└─────────────────────────┘
            │                                   │
            ▼                                   ▼
        ┌──────────────────────┐
        │    Conclusions       │
        └──────────────────────┘
                   │
                   ▼
        ┌──────────────────────┐
        │  Recommendations     │
        └──────────────────────┘
```

Fig. I - 1
The Study Methodology

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(a) The first step in the study was to define the criteria that has to be used in the analysis.

(b) Data about the potential effectiveness of using simulators was gathered from the I.A.F. Headquarters and a large group of I.A.F. pilots (58). This data was the foundation of developing a way of measuring flying training effectiveness.

(c) Data about the existing way of computing training cost and actual values was provided by the I.A.F.

(d) With the above-described data, a model to examine the two questions that are the foundation of this study was developed.

(e) Three communities in the I.A.F., jets, helicopters, and transports, have been chosen for the purpose of demonstrating the cost-effectiveness model.

Finally, the author presents some conclusions on the way that the two basic questions have to be examined, and on the results of the training cost-effectiveness analysis in the three groups.

C. THESIS ORGANIZATION

Chapter II provides a background on flight simulators including historical development, technology development, degree of fidelity, and the pros and cons of using simulators during the process of selecting the proper mix of training hours. Chapter III develops a methodology to analyze the cost effectiveness of using simulators, while Chapter IV demonstrates the use of the analysis in the three I.A.F. groups (Jets, Helicopters, and Transports). Finally, conclusions are summarized in the fifth chapter.

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II. FLIGHT SIMULATORS - AN OVERVIEW

A. HISTORICAL DEVELOPMENT

The historical development of flight simulators seems to
have followed, step-by-step, the development of the airplane
itself. The requirement for such a development was stimulated
by the hazards of flying, the skills required to pilot the airplane,
the need for a training aid to supplement pilot instruction
and, in the last decades, by tne high cost of flying the jet
airplanes.

Prior to World War I, a training device which came to be
known as the "Penguin" was developed. It was a stubbed-winged
aircraft capable of moving across large open spaces, but incapable
of leaving the ground. [Ref. 1]

During the first war a training device which was produced
in France used an aircraft fuselage based on a pivotal mount
and incorporated compressed air which produced variations of
response and aerodynamic feel with variations in speed. [Ref. 2]

In 1924, two English research workers, Reid and Burton,
evaluated the importance of full cockpit simulation by measuring
responses of pilots in a modified aircraft fuselage with functioning
displays and controls. It was concluded that devices which
required pilots to make responses on the ground to those made
while airborne could be used to: (1) test the pilot's ability
to fly and land successfully, (2) assess the rate of acquisition
of flying skills, (3) train pilots on those particular motor

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skills necessary for aircraft controllability, and (4) classify

subjects for different forms of flying services. [Ref. 2]

In 1929, Roeber, a German inventor, proposed an apparatus

for instruction in the navigation of vehicles in free space,

utilizing a hydraulic system which would reproduce the physical

movement of an airship like the motion systems of some present-day

simulators.

Edwin Link completed the development of the first Link-Train,

in 1929, which later became the famous ground trainer during

the Second World War. [Ref. 1]

After the war, the development of computer technology, the

increasing cost of flying training due to the high gas consump-

tion of the jet engines and the complexity of the new airplanes

accelerated the design and use of the flight simulators. During

the last two decades, a major step has been taken in using the

simulators. It has been changed from an instrument trainer

to a visual trainer. The trainee pilot is no longer limited

to a low degree of fidelity that is achieved by the instruments'

reactions and by 3-6 degrees of motion freedom. Nowadays, a

higher degree of fidelity is achieved by various techniques

of visual simulation.

In the I.A.F., the first big step toward using these simulators

was done after the 1967 War, during the years in which a new

generation of airplanes appeared in the airspace over the country.

The F-4 jet fighter, the CH-53 helicopter, and the C-130 transport

were much more avionics-oriented than their ancestors. Those

new airplanes were also much more expensive, considering the

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flying hour cost. Step-by-step with the increasing power and
capacity of the digital computers in those days, the 3-6 degrees
of motion freedom simulators became an attractive supplement
to the basic flying training tasks: procedures, emergencies,
instruments and avionics.

The next step in using simulators was done in the late 1970's
and the early 1980's as a result of losing about 75% of the
training airspace over the Sinai Desert, which was an ideal
military training space. The shrinking training space made
the airspace over Israel one of the most crowded airspaces in
the world. Many tactical training tasks such as low altitude
high speed navigation have no space in which to be performed.
The new restrictions on training pushed the I.A.F. to a new
era of developing the use of simulators as a tactical training
device, a concept that had high probability to be accomplished
by the introduction of high fidelity visual simulators in the
market.

Since the appearance of the visual simulators, the attitude
of the fliers toward the simulator has been changed, no longer
hating the simulator, but having a great respect for it as the
major tool to improve tactical performance of the pilot.

The motivation for the next step of using simulators in
the training mix is rooted in the great effect that the cost
of flying hours has on the country's economy. For many years
(and this is not going to be changed) air superiority has been
one of the major components in the country's defense concept.
The air superiority can be achieved by the technical performance

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of the flying weapon systems and, mainly, by the air crews who are responsible for implementing the technical performance.

The function that describes the fliers quality is dominated by one important variable - total training hours. Those training hours are also a dominant variable in the defense budget function. Introducing the simulator in the training mix has the potential of balancing the way that the training hours affect the budget function, without changing the power of the training in the quality function.

B. SIMULATORS' DEGREE OF FIDELITY

The main performance criterion in the process of designing the simulator as a flight training device is the simulators' degree of fidelity. Degree of fidelity is the term that is used to describe what part of the pilot's real world is represented by the simulator, e.g., the famous old Link Simulator had a very low degree of fidelity, because it represented to the pilot only the instruments in the cockpit, with nothing of the world outside the cockpit or any of the physical forces that influence the pilot during a real flight. Having such a low degree of fidelity, the simulator then could be used mainly for procedures training.

Later on, when motion was introduced with the simulators, a few of the physical and physiological forces that affect the pilot in a real flight were simulated, and the use of such a simulator could be expanded to training tasks such as instrument flight.

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Ten years ago, technology began to move toward the use of computers to create images. Unlike model boards, Computer Generated Images (CGI) simulators can be reprogrammed to create a variety of terrains and can also picture other aircrafts for combat training. The first step involved in the computer generated image system is to create the data base. Basic terrain contours are generally derived from digitized topological maps, and realistic details such as airports, roads and vegetation are added either by hand or by automatically duplicating standard models. The entire data base is stored in the computer as a large series of polygons. During the second step, the computer calculates the position and orientation of the simulated aircraft, decides what can be observed from this point and altitude, and then uses the data base to create thousands of colored and shaded polygons. Then comes the last step in which the images are sent to the display devices which project the images on a dome-like screen surrounding the forward portion of the simulator cockpit. [Ref. 2]

To increase details and improve an image in the computer generated images method, the number of edges that are used to define a scene is increased. As a result, the capacity and processing speed requirements from the hardware increase and the image generator becomes the main bottleneck in the simulation process. [Ref. 2]

The main way that simulator manufacturers are improving the realism of the data base without narrowing the above-described bottleneck is through "texturing." texturing is "painting"

patterns onto the polygons to disguise their blockiness. For
example, in low level flight, trees look like abstract sculptures
using the conventional computer generated images method; however,
painting a pattern over each small square or "cell," one looks
like a real tree. The patterns themselves are generated in
advance either from photographs of real objects or by fractals.
Fractals are patterns created by breaking up a surface into
smaller and smaller irregular shapes that look the same at every
scale. Since the parts of the polygon not covered by the pattern
are transparent, the tree appears to have a ragged edge, rather
than the blocky one of the polygon. In addition, as the viewer
moves by the tree or other object, the image generator blends
the pattern of one face with that of another coming into view
so that a smooth, three-dimensional effect is created. [Ref. 3]

The visual simulators which use the Computer Generated Images
and the Texturing methods put the degree of fidelity to a level
that provides exact perspectiveness, near real time display
of static and moving objects, quick visual environment changes
or modifications, unlimited rate of maneuverability, and a relatively
large area of flight coverage.

The existing degree of visual simulators' fidelity enable
the users to introduce the simulator as a training device for
a wide range of tactical training tasks such as air-to-air and
air-to-ground combat maneuvers against active environment, air
refueling and Nap on Earth navigation for helicopters.

The next generation of simulators moves from computer graphics
to photographs that are taken by an aircraft that flies over

the area that has to be simulated. The photographs are scanned
onto a videodisc, and then, during the training simulator flight,
the computer predicts what photographs must be called up to
represent the scene. Each photo is then distorted in orientation,
scale and tilt to correspond with the position and direction
of the simulated aircraft at a given instant. [Ref. 3]

The real-world photographs, combining with expanding and
improving the display system, will push the degree of fidelity
to a near real-world level, in which pilots can use the simulator
as an operational training device. For example, a few hours
before an operational mission, the pilot will use the simulator
to train himself on the final leg of an air-to-ground mission,
using a data base that consists of photographs that have been
taken recently by a reconnaissance aircraft or by a satellite.

Following the image generation and display improvements,
the mechanical clumsiness of the simulators is reduced by turning
away from the standard approach of simulating accelerations
by actual motions of the simulator cockpit. The manufacturers
are using inflated seats and g-suits to simulate accelerations.
For a hard right bank, for example, the seat would push forward
against the pilot's back and the left side of the seat would
inflate. [Ref. 3]

Finally, it has to be mentioned that for many basic flying
training tasks, the non-visual simulator still produces a high
degree of fidelity and is relatively cheap to use.

C. ADVANTAGES AND LIMITATIONS OF USING FLIGHT SIMULATORS

The advantages and limitations of using the simulator as a flying training device need to be considered before going into the process of selecting the proper mix of training. The advantages provided by using simulators include:

(a) A pilot can gain from experience without paying the consequences for a wrong decision or bad performance.

(b) A pilot has the opportunity to train in situations that are not available in the real training environment, but are expected to be part of the real operational environment.

Examples:

(1) Air-to-ground task against active surface-to-air missiles site.

(2) Landing in a low ceiling/low visibility condition.

(c) The pilot has the opportunity to be trained in emergency procedures that are not safe enough to be part of the real flying training.

(d) Time can be compressed -- making the time the pilot spends in the simulator more efficient, e.g., a final instrument approach for landing can be repeated without the real-world need to fly after every landing all the way back to the initial point.

(e) Feedback is immediate and usually much more accurate than in the real flying training. Results are not judged by the trained pilots or by the instructors, but measured and represented by the simulator on the basis of well-defined measurements of effectiveness (MOE).

(f) Cost saving is built in. A simulator training hour costs about 5%-25% of the relating training flying hour.

The limitations of using simulators include:

(a) A simplistic view of the real world may result from the simulator performance and the way of using it. In such a case, negative learning can occur in which the pilot will find himself using the wrong tactics or flying his plane in the wrong way for a specific real-world situation.

(b) Confusion may be created by the easiness of introducing overly complex situations.

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(c) Although they are less expensive than flying hours, the absolute cost of using simulators is gradually increasing and, in contrast to airplanes, simulators are used only for training.

Balancing the pros and cons of using simulators has to be done by examining the effectiveness of the simulator in accomplishing the training tasks, the cost of using the simulator to accomplish the training, and then by a cost-effective analysis which considers the simulator as a component in the training mix. The result is the proper mix of flying and simulator hours.

III. TRAINING COST EFFECTIVENESS METHODOLOGY

A. GENERAL

The following analysis describes a suggested way of answering the two basic questions presented in the introduction:

  (a) Is the existing mix of training, flying and simulator hours cost effective?

  (b) What is the cost-effective potential mix of flying and simulator hours?

Two factors are usually involved in the process of cost-effectiveness analysis: (1) cost and (2) effectiveness. Relating cost to effectiveness is the easiest part of such an analysis and can be done either by fixing the cost and maximizing the effectiveness or by fixing the effectiveness and minimizing the cost. Much less obvious is the way of determining the cost and effectiveness of the system in examination or, in other words, how we measure the cost and the effectiveness of the system - in this case, how we measure the cost and the effectiveness of a certain mix of flying and simulator training hours.

In order to provide a way of measuring the cost and effectiveness, and relating them into a cost-effectiveness analysis that leads to answering the above questions, a model is developed and described in this chapter. Two assumptions are at the foundation of this model:

  (a) The existing level of effectiveness in the training of the I.A.F. air crews is also the required level of effectiveness.

(b) Any large scale of training mix effectiveness experiments
are impossible to execute. Using existing results of
such experiments in the U.S.A.F., U.S. Navy and U.S. Army
is limited due to variations in the effectiveness require-
ments between the I.A.F. and the various U.S. flying
forces.

The flow chart in Fig. III - 1 describes the steps involved

in developing and utilizing the model.

```
          ┌──────────────────────────────┐
          │          Define the          │
          │ cost-effectiveness criterion │
          └──────────────────────────────┘
                          │
                          ▼
      ┌────────────────────────┐         ┌──────────────────────┐
      │ Effectiveness submodel  │◄────────│  Effectiveness data  │
      └────────────────────────┘         └──────────────────────┘
                          │
                          ▼
         ┌──────────────────┐              ┌──────────────────────┐
         │  Cost submodel    │◄─────────────│      Cost data       │
         └──────────────────┘              └──────────────────────┘
                          │
                          ▼
                        ╱╲
  yes               ╱        ╲
              ╱    Is the       ╲
          ◄──┤  existing mix     │
             ╲      cost        ╱
              ╲   effective   ╱
                 ╲          ╱
                    ╲    ╱
                      │  no
                      ▼
            ┌──────────────────┐
            │ Calculate the cost│
            │   effective mix   │
            └──────────────────┘
                      │
                      ▼
            ┌──────────────────┐
 ──────────►│     Results      │
            └──────────────────┘
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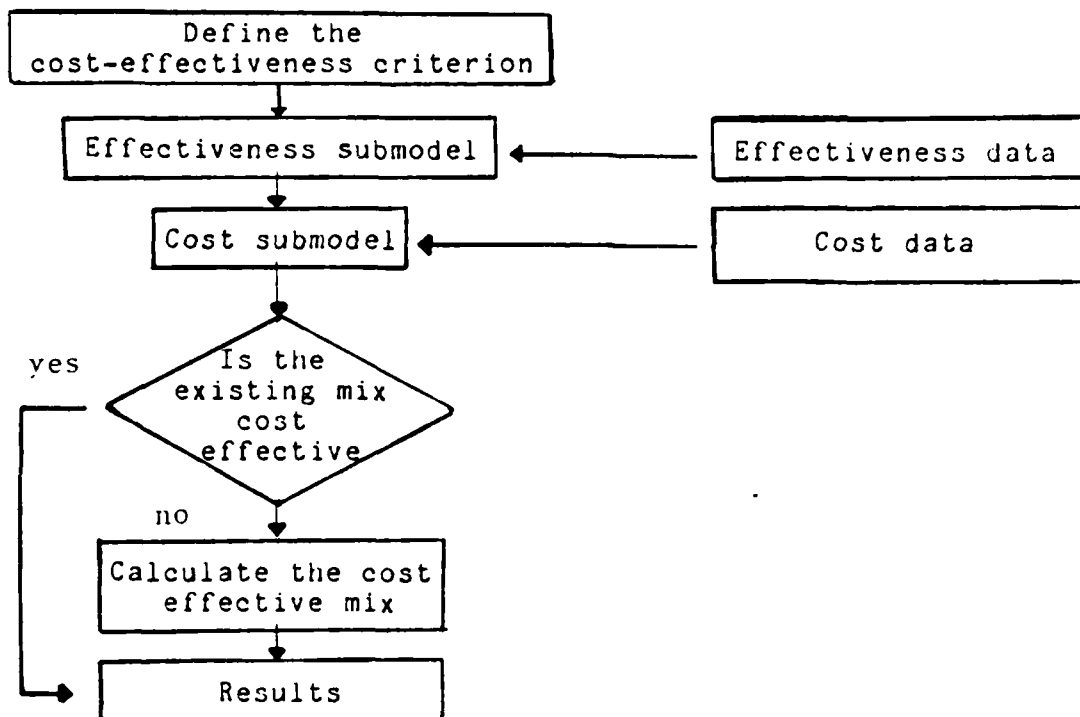
Fig. III - 1

The Training Cost Effectiveness Model - A Flow Chart

The following sections describe each step in the flow chart.

B. COST-EFFECTIVENESS CRITERION

The first step in the process of model developing was to

choose between the two common criteria for cost-effective analysis.

Fixing the effectiveness level and minimizing the cost was chosen

as the criterion in this model, and is due to the following

reasons:

(a) The difficulties involved in quantitatively measuring the effectiveness of a military aviator. The real-world environment of the pilots is not the air-to-ground or air-to-air range, but the airspace over the enemy territories in which pure flying skills are only part of the game. We are usually able to measure air crews' performances only with respect to the "pilot" part of the term "fighter pilot," but we are rarely able to measure the "fighter" performances.

(b) The basic assumption that the existing effectiveness level of the air crew, an effectiveness that is achieved by the existing mix of flying and simulator training hours, is also the required effectiveness level.

This assumption enables us to bypass the difficulties involved

in measuring effectiveness of different combinations of flying

and simulator hours. We only have to find out the various combin-

ations that give us the same effectiveness as we have now, and

then compute the cost of each combination and choose the least

cost combination.

C. TRAINING EFFECTIVENESS SUBMODEL

After deciding that the effectiveness level is constant

in the model, we have to construct a curve which is equivalent

to the isoquant curve from microeconomic theory. An isoquant

is a contour line which shows all combinations of two inputs

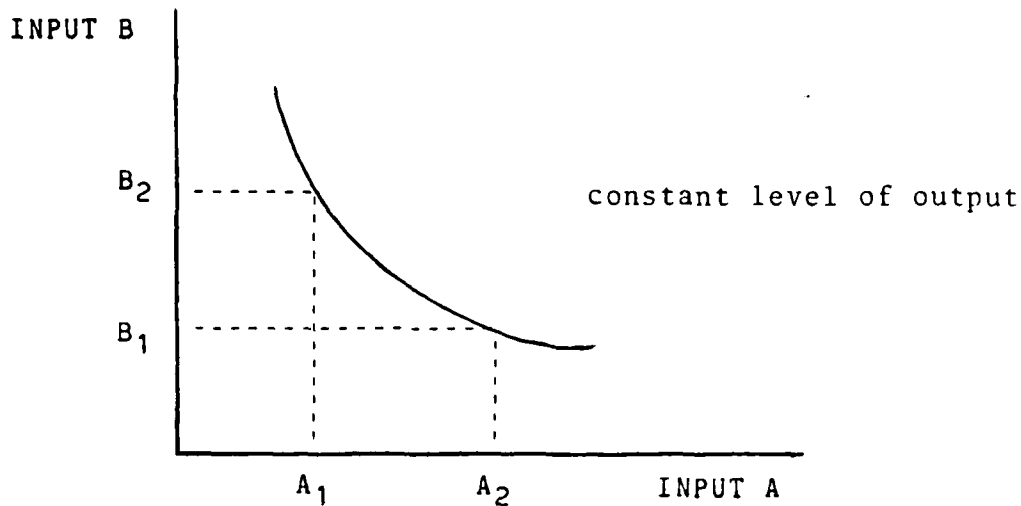that will produce a given level of output. (See Fig. III -

2)

INPUT B

B$_2$

B$_1$

constant level of output

A$_1$ A$_2$ INPUT A

Fig. III - 2

The Isoquant Curve

The mix of input B$_2$ and A$_1$ gives the same output level of
the mix B$_1$ and A$_2$. The slope of the isoquant is defined by
the marginal rate of technical substitution (MRTS) which is
the rate at which one input can be substituted for another while
output remains constant. Thus, along the isoquant, the total
differential of the output function is equal to:

$$dE = \frac{\partial E}{\partial FH} * dFH + \frac{\partial E}{\partial SH} * dSH = 0$$

In our model, output level is the effectiveness level, and
the two inputs that describe the effectiveness level are yearly
training flying hours per pilot and yearly simulator hours per
pilot.

TRANSFER EFFECTIVENESS RATIO (TER) is the term that is
used in various researches on training cost effectiveness to

describe the marginal rate of technical substitution of two
training devices.   Since it was first mentioned in 1971, by
Roscoe and Povenmire in the Human Factor Journal [Ref. 4], the
TER has been used to describe the linear relationship between
the time in the trainer and the time in the operational environment.
However, it is obvious that, in the case of the simulator and
flying hours mix, this relationship is not linear: the first
hour in the simulator is "worth" much more flying hours than
the tenth hour.   In microeconomic terms, a simulator hour and
a flying hour are not perfect substitutions.

Figure III - 3 describes the steps in constructing the
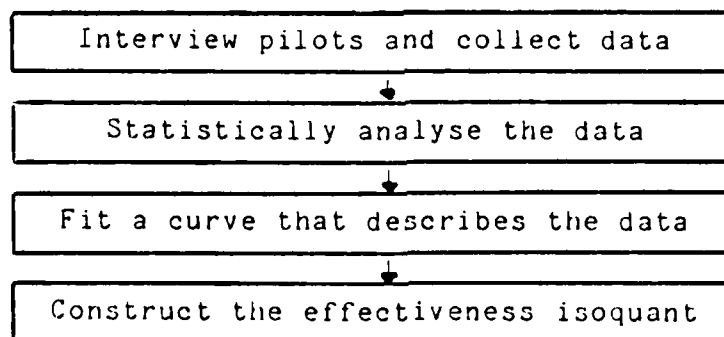Effectiveness Isoquant.

```
+-------------------------------------------+
|    Interview pilots and collect data      |
+-------------------------------------------+
                     |
+-------------------------------------------+
|      Statistically analyse the data       |
+-------------------------------------------+
                     |
+-------------------------------------------+
|    Fit a curve that describes the data    |
+-------------------------------------------+
                     |
+-------------------------------------------+
|   Construct the effectiveness isoquant    |
+-------------------------------------------+
```

Fig. III - 3

Constructing the Effectiveness Isoquant - A Flow Chart

(a)   Interview pilots and collect data - After deciding which
      group in the A.F. is examined by the model, pilots from
      this group are asked to express their opinions on the
      various combinations of flying and simulator hours subject
      to the existing level of effectiveness.   Each of the
      pilots is given a table (Table III - 1) that contains
      the existing yearly mix of flying and simulator hours
      of himself, and a range of +20% - -20% of his yearly
      flying hours.   The existing level of effectiveness is
      represented by the existing mix of flying and simulator

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hours and to the range of flying hours. The pilot has
to fill a range of simulator hours that will keep him
on the same effectiveness level.

TABLE III - 1

TRAINING MIX - A PILOT VIEW

Yearly Flying Hours	80	85	90	95	100	105	110	115	120
Yearly Simulator Hours					6				

(b) Statistically analyze the data - Performed by computing
the mean and the 95% confidence intervals to the related
simulator hours to each of the flying hours data points.

Mean $\overline{SH} = \dfrac{\Sigma_1^n SH_i}{h}$

Variance $= S = \sqrt{\dfrac{\Sigma_1^n (\overline{SH} - Sh_i)^2}{n - 1}}$

Upper 95% confidence bound $= \overline{SH} \pm \dfrac{t^{\alpha/2} S}{\sqrt{n}}$

SH - Simulator hours that are required to be used with a given
number of flying hours.

n - number of pilots opinions on the required training simulator
hours to the given number of flying hours.

$t_{/2}$ - is the tabulated t value cutting off a right-tail area
of $^{\alpha}/2$, with n-1 degree of freedom.

Table III - 2 is an example of the way in which the statistical

analysis on the effectiveness data has to be summarized.

TABLE III - 2

TRAINING MIX - STATISTICAL SUMMARY

Yearly Flying Hours	70	75	80	85	90	95	100	105	110	115	120
Yearly required simulator hours - average							6				
Yearly required simulator hours - upper 95% C.I.							6				
Yearly required simulator hours - lower 95% C.I.							6				

(c)   Curve fitting is performed to the average, to the upper
      95% and to the lower 95% C.I. The criterion that is
      used to fit the curve is the least R square criterion
      and the basic function that describes the curve is the
      power function $Y = ax^b$. The power function makes the
      computations relatively easy by linearization of the
      function to the form of $\log Y = \log a + b*\log x$, and
      then using the linear regression as a model to compute
      and R square.

(d)   Construct the effectiveness isoquant - The three curves
      that have already been fitted are constructed as shown
      in Fig. III - 4.

Simulator
hours

_____ - Average
------- - Upper 95% C.I.
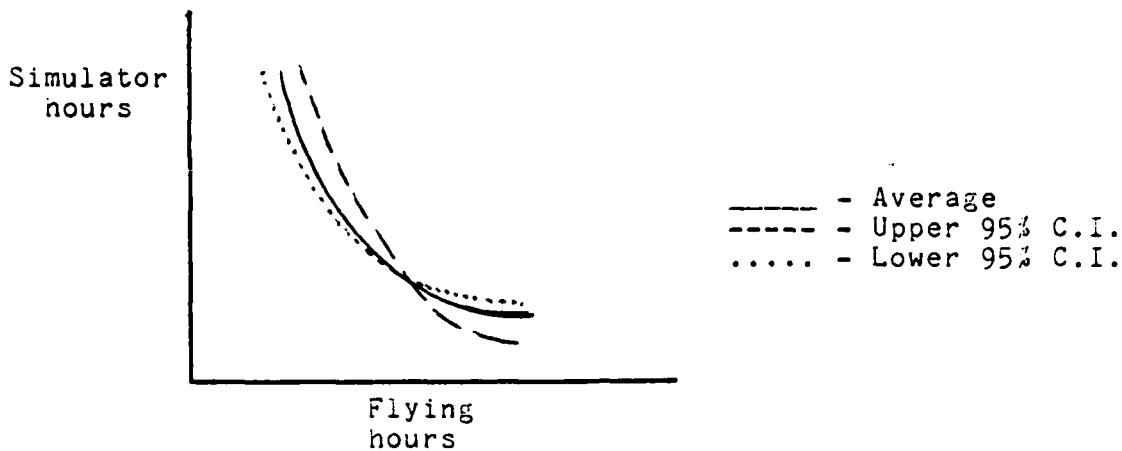..... - Lower 95% C.I.

Flying
hours

Fig. III - 4

The Effectiveness Isoquants

The slope of the curves represents various ranges of the Transfer Effectiveness Ratio. In order to stay on the "safe side," only the upper 95% C.I. will be used in the rest of the analysis. This is a way to compensate the weakness of the TER computations, a weakness that is rooted in the absence of empirical data.

D.   TRAINING COST SUBMODEL

The cost submodel has the function of determining the cost of training along the 95% upper C.I. effectiveness isoquant that has been constructed in the effectiveness submodel. For our purposes, the cost of training is a function of the average cost of flying hour, average cost of a simulator hour, yearly average flying hours per pilot, yearly average simulator hours per pilot, and the number of pilots in the groups under examination.

Figure III - 5 describes the cost submodel steps.

27

```
┌─────────────────────────┐
│ Cost data               │
│                         │
└───────────┬─────────────┘
            │
            ▼
┌─────────────────────────┐
│ Compute average cost of a│◄──────────────────┐
│      flying hour        │                    │
└───────────┬─────────────┘                    │
            │                                  │
            ▼                                  │
┌─────────────────────────┐        ┌──────────────────────────┐
│ Compute average cost of a│◄───────│                          │
│     simulator hour      │        │  Performed Sensitivity   │
│                         │        │       Analysis           │
└───────────┬─────────────┘        └──────────────────────────┘
            │                                  │
            ▼                                  │
┌─────────────────────────┐                    │
│ Show the function that  │◄───────────────────┘
│ describes the training  │
│ cost along the 95% upper│
│ C.I. effectiveness isoquant│
└─────────────────────────┘
```
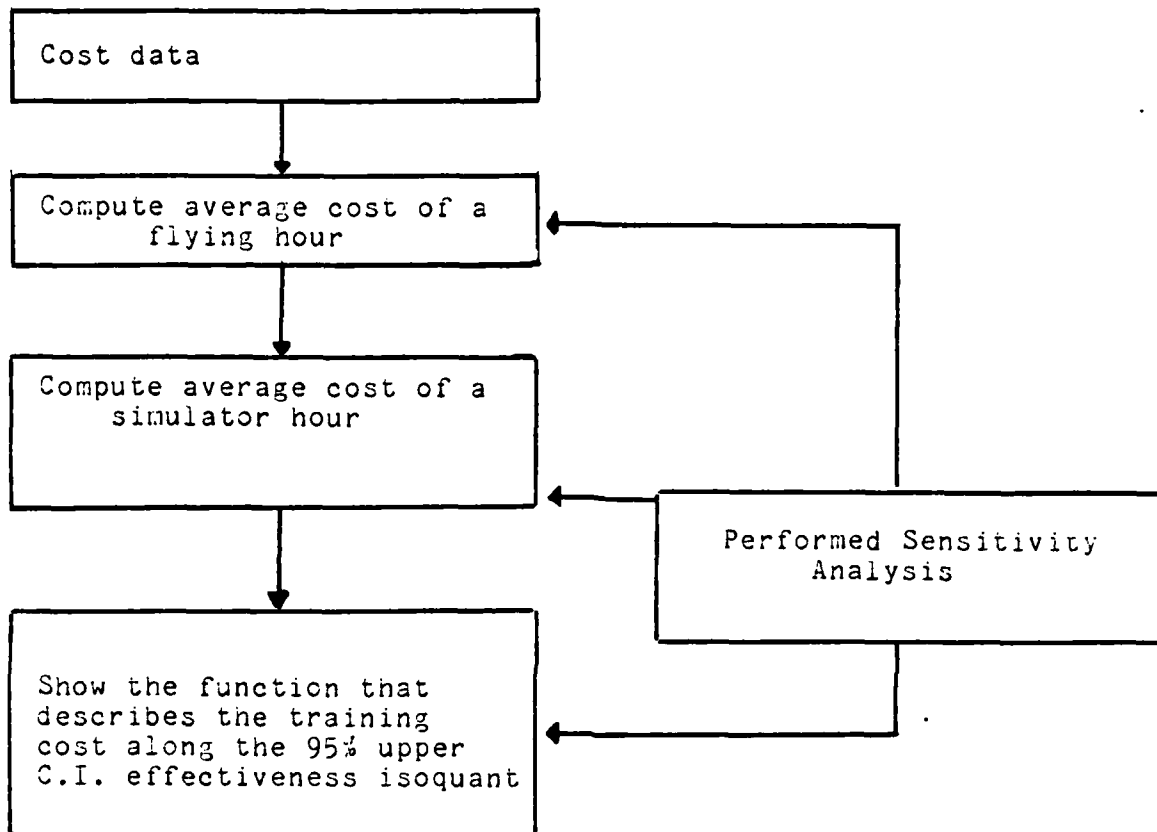
Fig. III - 5

Cost Submodel - A Flow Chart

(a) Cost data - The cost data which is used in the I.A.F. is limited to a constant average flying hour cost and to no data on the average cost of a simulator hour except from those groups that get their simulator training outside the country.

(b) Average cost of a flying hour - As mentioned above, the existing way of computing the average cost of a flying hour implies a constant average cost, which is a reasonable assumption while considering a short range of total flying hours. Built in our model, a wide range of total flying hours is considered, so a different model of computing the average cost of a flying hour is needed: a model in which the average cost varies over the range of total flying hours. Instead of using a model which is not in existence, a sensitivity analysis is performed in our cost submodel on the existing data. The technique that is used in the sensitivity analysis is based on the learning curve theory: each time the total flying hours we produced is doubled, the cost per flying hour is reduced to a constant percentage of its previous cost. The formulation of the learning curve theory results in a power function and the implementation of this function for our sensitivity analysis results in the following equation:

$$A_c = \frac{C * X^{-b}}{FH^{-b}}$$

A_c - The average cost of a flying hour related to a total of X flying hours.

C - The existing cost of a flying hour which is based on the data

FH - The total existing yearly flying hours in the examined group

29

b - Is the power term that describes the percentage reduction in the average cost of a flying hour by doubling the total flying hours.

$$b = \frac{\log \ .\% \ of \ cost \ reduction}{\log 2}$$

The following example demonstrates the way of performing the sensitivity analysis on the cost computation:

(1) The existing cost of a flying hour (C) = $5000.

(2) Total yearly flying hours in the examined group (FH) = 2000 hours.

(3) Estimated percentage average cost reduction while doubling total flying hours = 10%.

(4) Total yearly flying hours that we wish to compute the related average cost of a flying hour (X) = 1700.

$$b = \frac{\log \ .9}{\log \ .2} = .152$$

$$A_c = \frac{(5000) \ (1700^{-.152})}{2000^{-.152}} = \$5125.05$$

(5) Conclusion - By decreasing the total flying hours from 2000 hours per year to 1700 hours per year, the average cost of a flying hour is changed from $5000 to $5125.05.

(c) Average cost of a simulator hour - The same technique that was described in the sensitivity analysis of the average cost of a flying hour is used for the sensitivity analysis of the average cost of a simulator hour. In this case, due to the small numbers of total simulator hours in the present, and due to the fact that the cost data that we have is based only on the cost of training outside the country, it is assumed that any future combination of training hours will cause a reduction in the average cost of a simulator hour. This assumption leads to the following equation:

$$A_c = C_* X^{-b}$$

30

A_c = The average cost of a simulator hour relates to a total of X total simulator hours.

C = The average constant cost of a simulator hour in the present.

b = The power term that expresses the percentage reduction in the average cost of a simulator hour while doubling total yearly simulator hours.

The following example demonstrates the way of performing the sensitivity analysis on the simulator average cost computation:

(1) Existing cost of a simulator hour (C) = $500.

(2) The estimated percentage reduction in the average cost of a simulator hour while doubling total simulator hours - 5%.

$$b = \frac{\log .95}{\log 2} = -.074$$

(3) Total yearly simulator hours in the examined training mix (X) = 1000.

$$A_c = (500) * 1000^{-.074} = \$299.89$$

E. TOTAL TRAINING COST

The following equation describes the total yearly training cost:

$$C_t = (X_{fh} * A_{cfh} + X_{sh} * A_{csh}) P$$

C_t - Total yearly cost of training of the examined training mix.

X_{fh} - Yearly flying hours per pilot in the examined training mix.

X_{sh} - Yearly simulator hours in the examined training mix.

A_{cfh}- Average cost of a flying hour in the examined training mix.

P - Number of pilots in the group.

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The final results of the cost submodel is a graph that shows the relation between the mix of training to its cost. The number of curves in the graph are determined by the number of sensitivity analyses that we want to perform. (See Fig. III - 6)
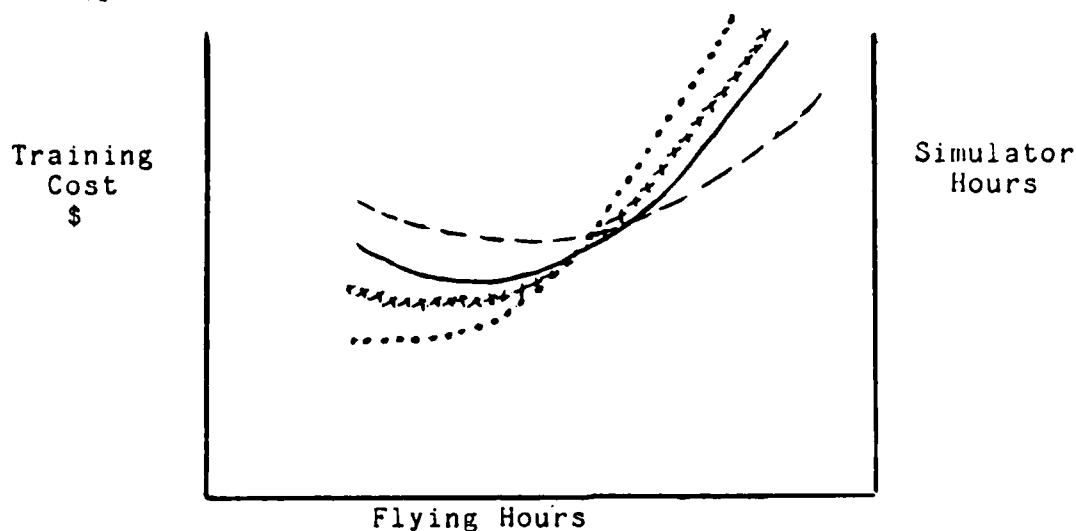
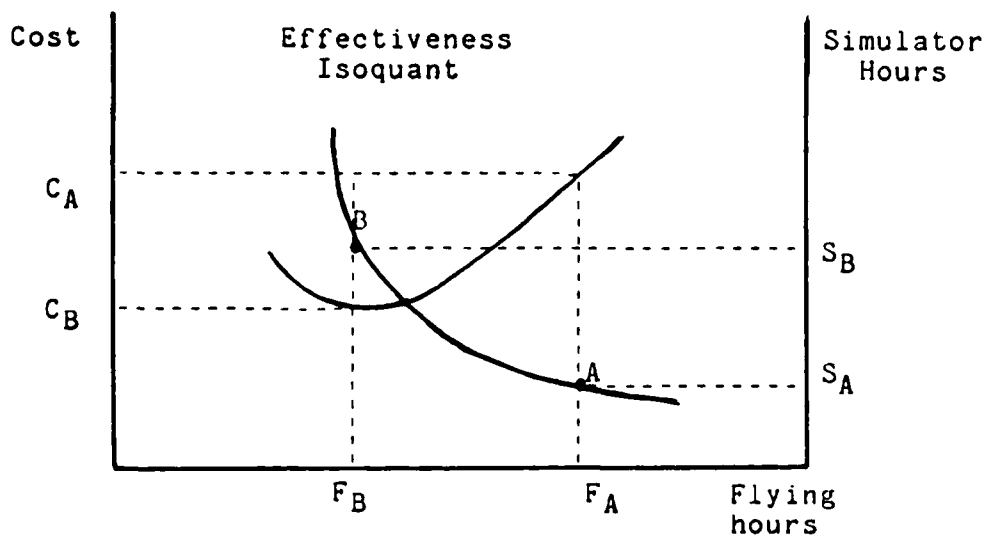Training
Cost
$

Simulator
Hours

Flying Hours

Fig. III - 6

Training Cost Curves

Fig. III - 6 is an example of 4 different cost curves based on the following sensitivity analysis:

(a) _____ Constant average cost of a flying hour and a 95% learning curve in the average cost of a simulator hour.

(b) ----- Constant average cost of a simulator hour and 90% learning curve in the average cost of a flying hour.

(c) ***** Constant average costs of a flying and a simulator hour.

(d) ..... 95% learning curve in the average cost of a simulator hour and 90% learning curve in the average cost of a flying hour.

F. IS THE EXISTING TRAINING MIX COST EFFECTIVE?

Relating the effectiveness isoquant and the cost curves gives us the answer to our first question - "Is the existing training mix cost effective?"

(a) Point A represents the existing training mix.

(b) Point C_A represents the total cost of the existing training mix.

(c) Point B represents the least cost feasible mix of training.

(d) Point C_B represents the total cost of B mix.

(e) $C_A - C_B$ - is the dollar value of the difference between the existing training mix and the cost-effective training mix.

(f) $\left(\dfrac{C_A - C_B}{C_B} \right) 100$ - is the percentage expression to the existence level of cost effectiveness.

G.   THE COST EFFECTIVE TRAINING MIX

The final step in the model is defining the cost-effective
mix of training in the examined group. Although we are using
the least cost training mix for a given constant effectiveness
level as a criterion for the analysis, it is unrealistic to
make the least cost mix as the actual mix. The actual mix of
training is subject to various constraints which make the linear
programming technique as a way to arrive at the cost-effective
mix solution.

The flow chart in Fig. III - 3 illustrates the steps in
the process of solving the cost-effective mix by linear programming
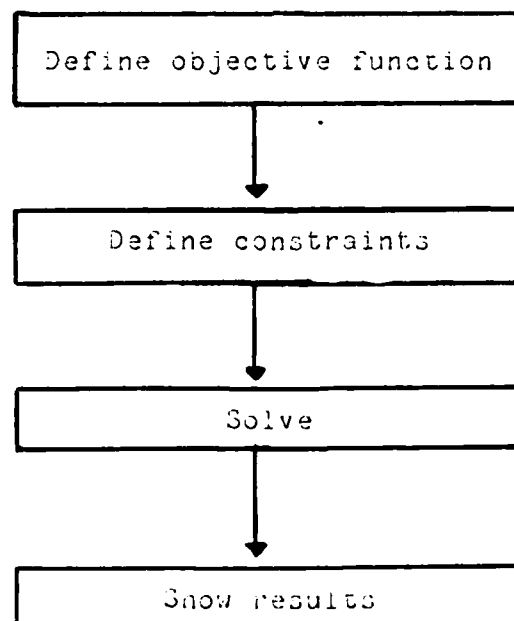techniques.

```
┌────────────────────────────────┐
│   Define objective function    │
└────────────────────────────────┘
                 │
                 ▼
┌────────────────────────────────┐
│       Define constraints       │
└────────────────────────────────┘
                 │
                 ▼
┌────────────────────────────────┐
│             Solve              │
└────────────────────────────────┘
                 │
                 ▼
┌────────────────────────────────┐
│          Show results          │
└────────────────────────────────┘
```

Fig. III - 3

Solving the Cost Effective Training Mix - A Flow Chart

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1. The objective function in our analysis is:

   Minimize $C_t = (X_{fh} * A_{cfh} + X_{sh} * A_{cfh})$ P

   C_t - Total yearly cost of training

   X_{fh} - Yearly flying hours per pilot

   A_{cfh}- Average cost of a flying hour

   X_{sh} - Yearly simulator hours per pilot as it has already been determined by the effectiveness isoquant function

   A_{ssh}- Average cost of a simulator hour

2. The constraints are usually defined by management author-
   ities. For example:

   - Number of pilot (P) is constant and not subject to change.

   - Yearly flying hours per pilot (Xfh) $\geq$ yearly simulator hours per pilot (X_{sh})

   - Total increasing in training $\leq$ 50%

3. Solving the problem is done by linear programming computerized packages.

Depending upon the number of sensitivity analyses that have been performed along the analysis, we will get not a single solution but a range of cost effective and feasible solutions.

The next chapter is dedicated to illustrate three examples of using the model to analyze training cost effectiveness in three of the I.A.F. communities.

IV. TRAINING COST EFFECTIVENESS ANALYSIS - AN ILLUSTRATION

A. GENERAL

In this chapter, the training cost effectiveness model that
was described in the previous chapter will be illustrated.
For the purposes of this illustration, 3 groups of the I.A.F. will
be analyzed and compared:

(a) The training cost effectiveness of the Jet pilot.

(b) The training cost effectiveness of the Helicopter pilot.

(c) The training cost effectiveness of the Transport pilot.

By examining those groups, a low level of resolution and
an aggregate model is implied which is not the case when implementing
the model in reality. In reality, more specific training groups
have to be examined in order to get practical results. The
unclassified restrictions of this paper prevent an illustration
of the model in a higher resolution, so the numbers along the
analysis and the results of each of the analyses have to be
considered as a means to illustrate the use of the model and
as a low resolution picture of the training cost effectiveness
in each of the three groups. The unclassified restrictions
of the paper prevent the author also, from detailing numbers
of pilots, so the illustrated examples will stay on the level
of an individual pilot.

Each of the following sections is dedicated to each of the
three groups. The last section will summarize the results.

B. TRAINING COST EFFECTIVENESS – THE JET PILOT

Twenty jet pilots were asked to express their view on the Transfer Effectiveness Ratio of using simulators in their group without changing the effectiveness level. The existing effectiveness level is represented by an average of 100 yearly flying hours and 7 yearly simulator hours per pilot. Each of the pilots had to consider 4 levels of flying hours - 80, 90, 110, and 120. The summarized results are shown in Table IV - 1.

TABLE IV - 1

TRANSFER EFFECTIVENESS RATIO - JETS

Flying hours / Simulator hours	80	90	100	110	120
Average	124.00	48.75	7.00	4.80	3.45
Upper 95% C.I.	146.23	60.44	7.00	4.29	2.94
Lower 95% C.I.	101.77	37.06	7.00	5.32	2.96

Based on the above statistics, 3 effectiveness isoquants were fitted and are shown in Fig. IV - 1.

1. Effectiveness isoquant that is based on the average Transfer Effectiveness Ratio:

$$SH = \text{antilog } 20.1 * FH^{-9.47}$$

$$R^2 = 93.2\%$$

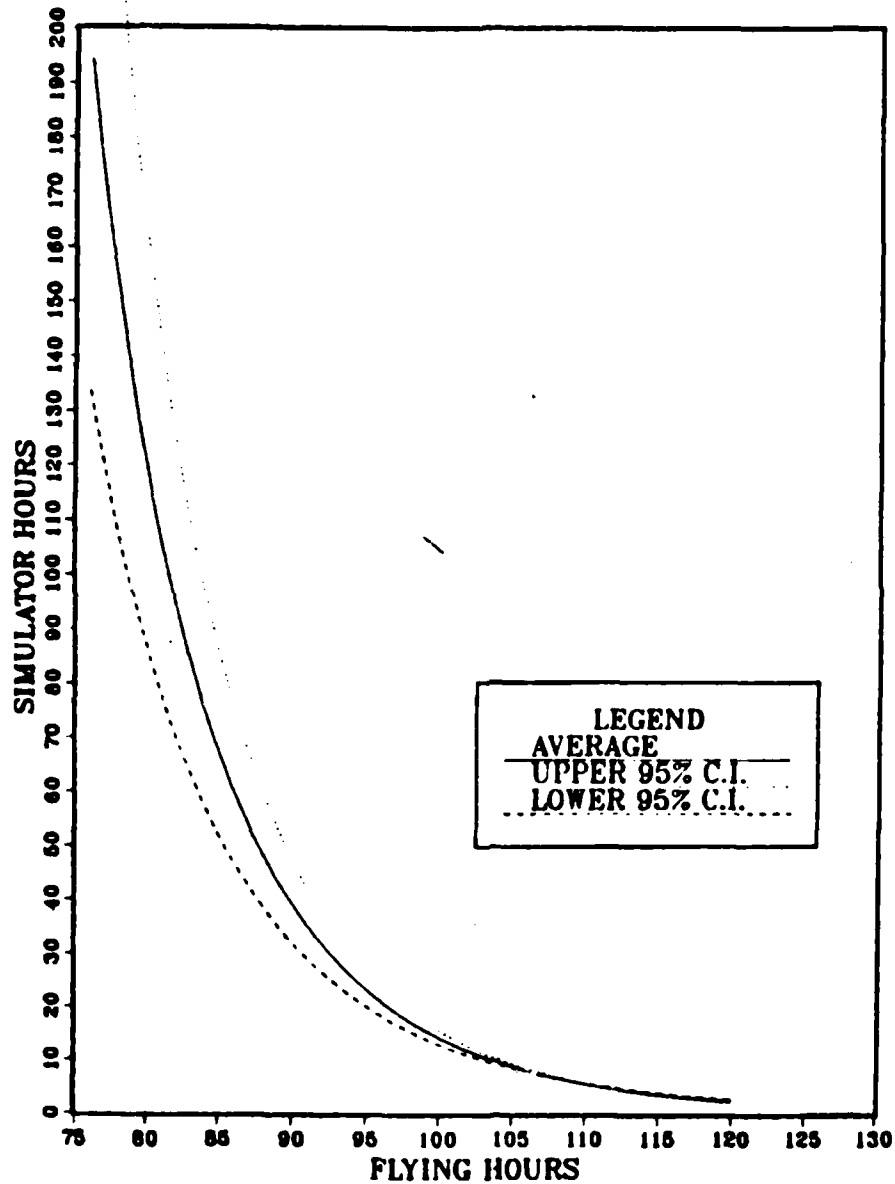# EFFECTIVENESS ISOQUANTS – JETS

Figure IV - 1
The Effectiveness Isoquants - Jets

38

SH - yearly simulator hours per pilot

FH - yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95% C.I. Transfer Effectiveness Ratio:

   $SH = antilog\ 22_*FH^{-10.4}$

   $R^2 = 93.6\%$

3. Effectiveness isoquant that is based on the lower 95% C.I. Transfer Effectiveness Ratio:

   $SH = antilog\ 18_*FH^{-8.44}$

The upper 95% C.I. effectiveness isoquant is used in the rest of the analysis.

The following average costs are used in the computation of total cost of training:

   (a) Constant average cost of a jet flying hour = $8567.

   (b) Average cost of a flying hour with a learning curve of 20%.

   (c) Constant average cost of a jet simulator hour = $564.

   (d) Average cost of a jet simulator hour with a learning curve of 90%.

Fig. IV - 2 shows four different cost curves based on the above methods of computing average training hour cost and how they relate to the yearly flying hours that are implied by the effectiveness isoquant.
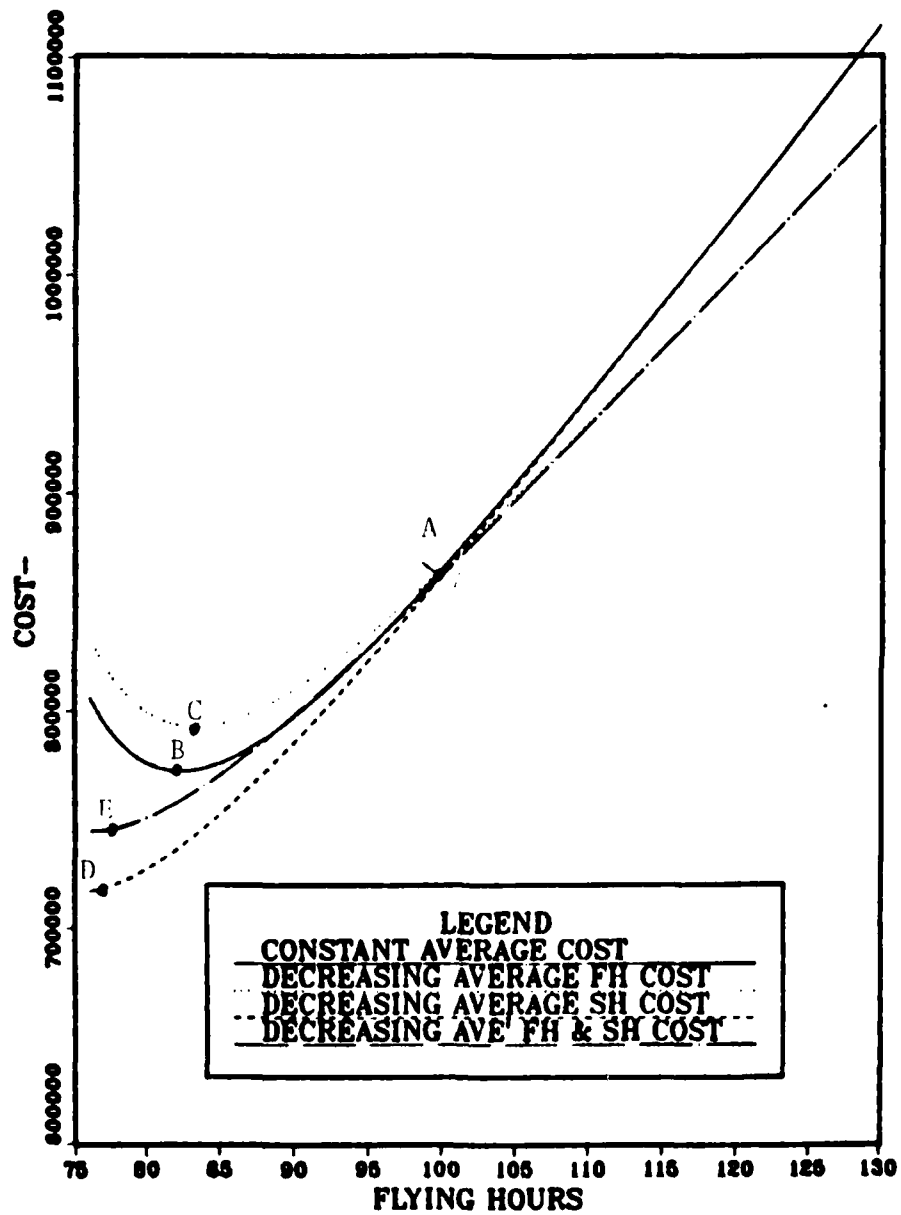
TRAINING COST – JETS

Figure IV - 2
The Training Cost Curves - Jets

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Point A represents the existing yearly cost of training a jet pilot.

$$C = 100 * 8567 + 7 * 564 = \$860,648$$

Table IV - 2 is a summary of points B-E on the graph.

TABLE IV - 2

COST EFFECTIVENESS - PRESENT JETS TRAINING MIX

Point	Method of Computing Average Cost		Least Cost Mix		Cost of	Cost
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours	Training	Effective-ness
B	constant	constant	82	124	$772,430	-$88,218
C	90% learning curve	constant	83	110	$793,528	-$67,120
D	constant	90% learning curve	77	240	$718,502	-$142,146
E	90% learning curve	90% learning curve	78	210	$746,488	-$114,160

The conclusion at this stage of the analysis is that, without considering any constraints, the jet pilot training is not cost effective by the range of $67,120 - $142,146, which is 8%-16% of the present cost of training.

Before concluding on the cost-effective mix and what can be really saved, two constraints will be presented as an example:

(a) Total yearly simulator hours cannot exceed total yearly flying hours.

(b) Total increase in yearly training hours cannot exceed 50% of the present training hours.

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Solving the problem of the least cost feasible training mix by linear programming techniques leads us to conclude that 87 flying hours and 67 simulator hours is the most cost effective training mix. Table IV - 3 summarizes the cost-effectiveness meaning of the training mix.

TABLE IV - 3

THE COST EFFECTIVE TRAINING MIX - JETS

Method of Computing Average Cost		Least Cost Feasable Mix		Cost of Training	Saving	
Flying Hour	Simulator Hour	Flying Hours	Simulator Hours		$	%
constant	constant	87	67	$783,117	$77,531	9%
90% learning curve	constant	87	67	$799,062	$61,586	7.2%
constant	90% learning curve	87	67	$765,272	$95,376	11%
90% learning curve	90% learning curve	87	67	$781,217	$79,431	9.2%

To conclude, $61,586 - $95,376, which is 7.2%-11% from the present cost of training, can be saved from the cost of training an individual jet pilot by changing the training mix from 100 flying hours and 7 simulator hours to 87 flying hours and 67 simulator hours.

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C. TRAINING COST EFFECTIVENESS - THE HELICOPTER PILOT

Twenty helicopter pilots were asked to express their views on the Transfer Effectiveness Ratio of using simulators in their group and without changing the existing training effectiveness. The existing effectiveness is represented by 80 yearly training flying hours and 20 yearly simulator hours on the average. Each of the pilots had to consider four ranges of flying hours - 60, 70, 90, and 100. The results are summarized in Table IV - 4.

TABLE IV - 4
TRANSFER EFFECTIVENESS RATIO - HELICOPTERS

Flying hours / Simulator hours	60	70	80	90	100
Average	158.25	74.25	20.00	13.30	10.20
Upper 95% C.I.	194.46	87.93	20.00	12.44	9.20
Lower 95% C.I.	122.06	60.57	20.00	14.16	11.19

Based on the above statistics, three effectiveness isoquants were fitted and are shown in Fig. IV - 3:

1. The effectiveness isoquant that is based on the average Transfer Effectiveness Ratio:
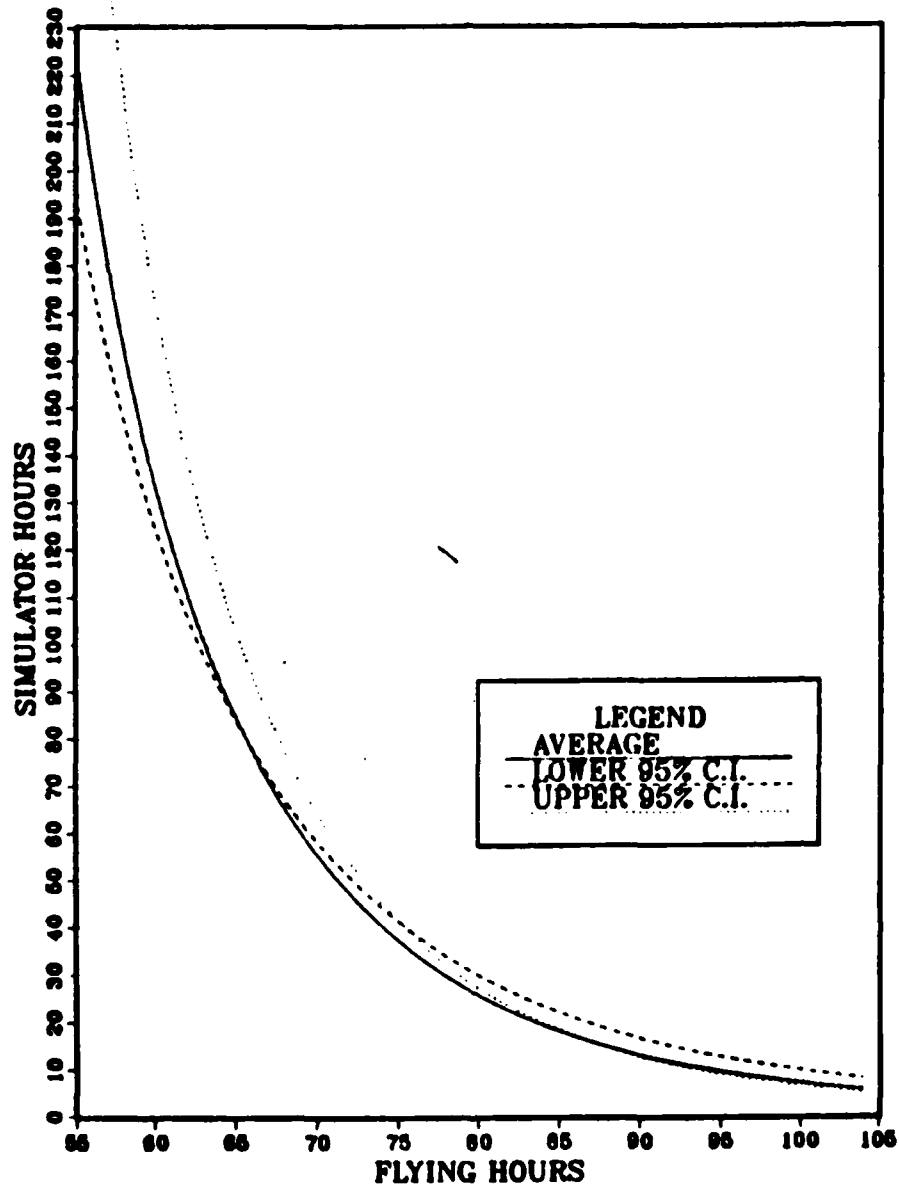
43

EFFECTIVENESS ISOQUANTS – HELO'

Figure IV - 3
The Effectiveness Isoquants - Helicopters

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SH = antilog $12.3 * FH^{-5.72}$

$R^2 = 95.7\%$

SH - Yearly simulator hours per pilot

FH - Yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95%
    C.I. Transfer Effectiveness Ratio:

SH = antilog $13.6 * FH^{-6.39}$

$R^2 = 95.8\%$

3. Effectiveness isoquant that is based on the lower 95%
    C.I. Transfer Effectiveness Ratio:

SH = antilog $10.9 * FH^{-4.95}$

$R^2 = 95.9\%$

The upper 95% C.I. isoquant is used in the rest of the analysis.
The following average costs are used in the total cost of training
submodel:

(a) Constant average cost of a helicopter hour - $2200.

(b) Average cost of a flying hour with a learning curve of
    90%.

(c) Constant average cost of a helicopter simulator hour -
    $562.

(d) Average cost of a helicopter simulator hour with a learning
    curve of 90%.

Fig IV - 4 shows four different cost curves based on the
above methods of computing average costs and how they relate
to the yearly flying hours that are implied by the effectiveness
isoquant.

Point A on the graph represents the existing yearly cost
of training a helicopter pilot:

$$C = 80 * 2200 + 20 * 562 = \$187,240$$
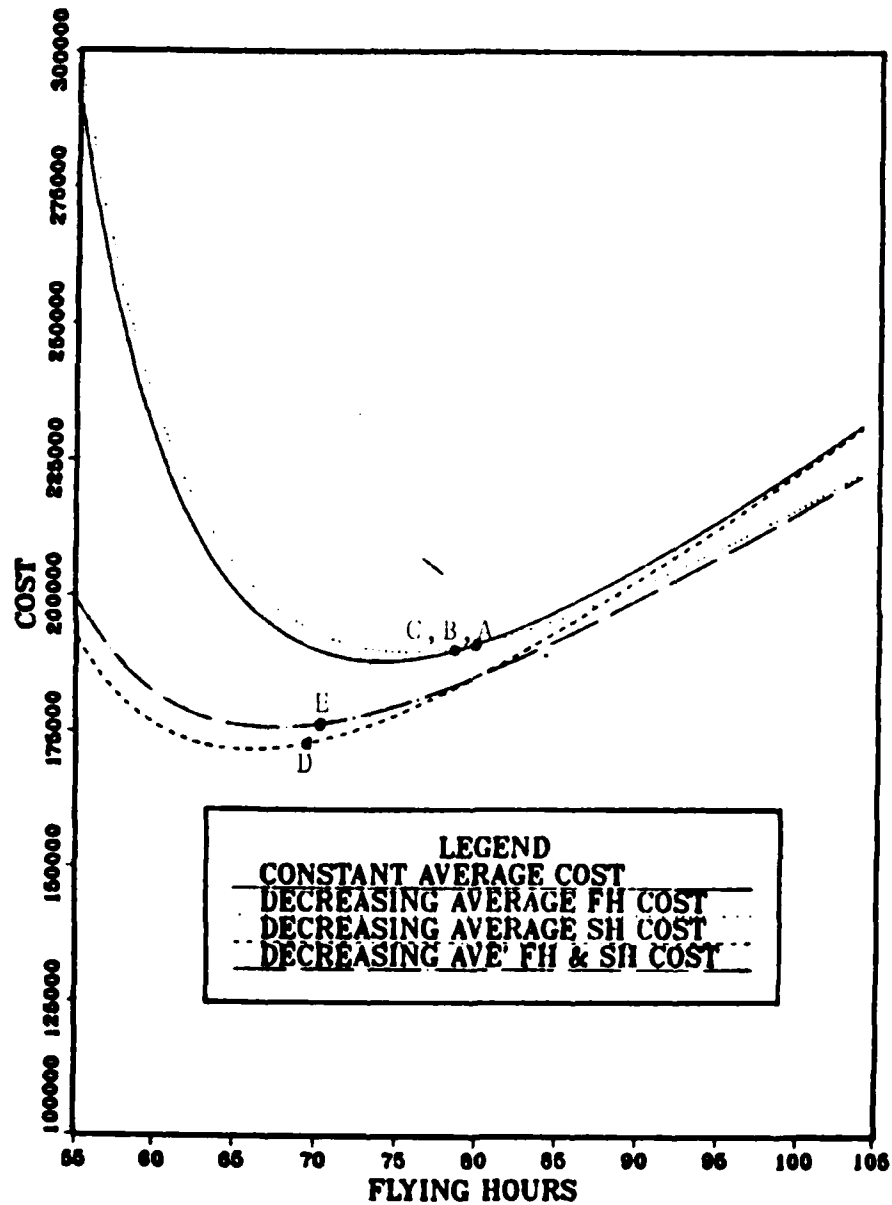
45

TRAINING COST – HELICOPTERS

Figure IV - 4
Training Cost Curves - Helicopters

46

Table IV - 5 summarizes the cost effectiveness in the heli-
copter community, which is represented by points B-E on the
graph.

TABLE IV - 5

COST EFFECTIVENESS - PRESENT HELICOPTERS TRAINING MIX

| Point | Method of Computing Average Cost | | Least Cost Mix | | Cost of | Cost Effec- |
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours	Training	tiveness
B	constant	constant	80	20	$187,240	1
C	90% learning curve	constant	80	20	$187,240	1
D	constant	90% learning curve	71	58	$173,784	-$13,456
E	90% learning curve	90% learning curve	72	53	$177,247	-$9,993

The conclusion at this stage of the analysis is that the
present mix of training in the helicopter community is cost
effective, and only by introducing a 90% learning curve in the
cost of an average simulator hour, $9,993 - $13,456, which is
5.3% - 7.2% of the present cost of training can be saved.

D.   TRAINING COST EFFECTIVENESS - THE TRANSPORT PILOT

Eighteen transport pilots were asked to express their views
on the Transfer Effectiveness Ratio of using simulators in their

group without changing the existing training effectiveness. The existing effectiveness level is represented by an average of 50 yearly flying hours and six yearly simulator hours per pilot. Each of the pilots had to consider four levels of yearly flying hours - 40, 45, 55, and 60. The results are summarized in Table IV - 6.

TABLE IV - 6

TRANSFER EFFECTIVENESS RATIO - TRANSPORTS

Flying hours Simulator hours	40	45	50	55	60
Average	35.25	15.45	6.00	3.50	2.35
Upper 95% confidence bound	42.67	17.75	6.00	2.20	2.00
Lower 95% confidence bound	27.83	13.33	6.00	4.09	2.70

Based on the above statistics, three effectiveness isoquants were fitted and are shown in Fig. IV - 5:

1. Effectiveness isoquant based on the average Transfer Effectiveness Ratio:

   $SH = antilog\ 12.5 * FH^{-6.86}$

   $R^2 = 98.8\%$

   SH = Yearly simulator hours per pilot

   FH = Yearly flying hours per pilot

2. Effectiveness isoquant that is based on the upper 95% confidence interval Transfer Effectiveness Ratio:
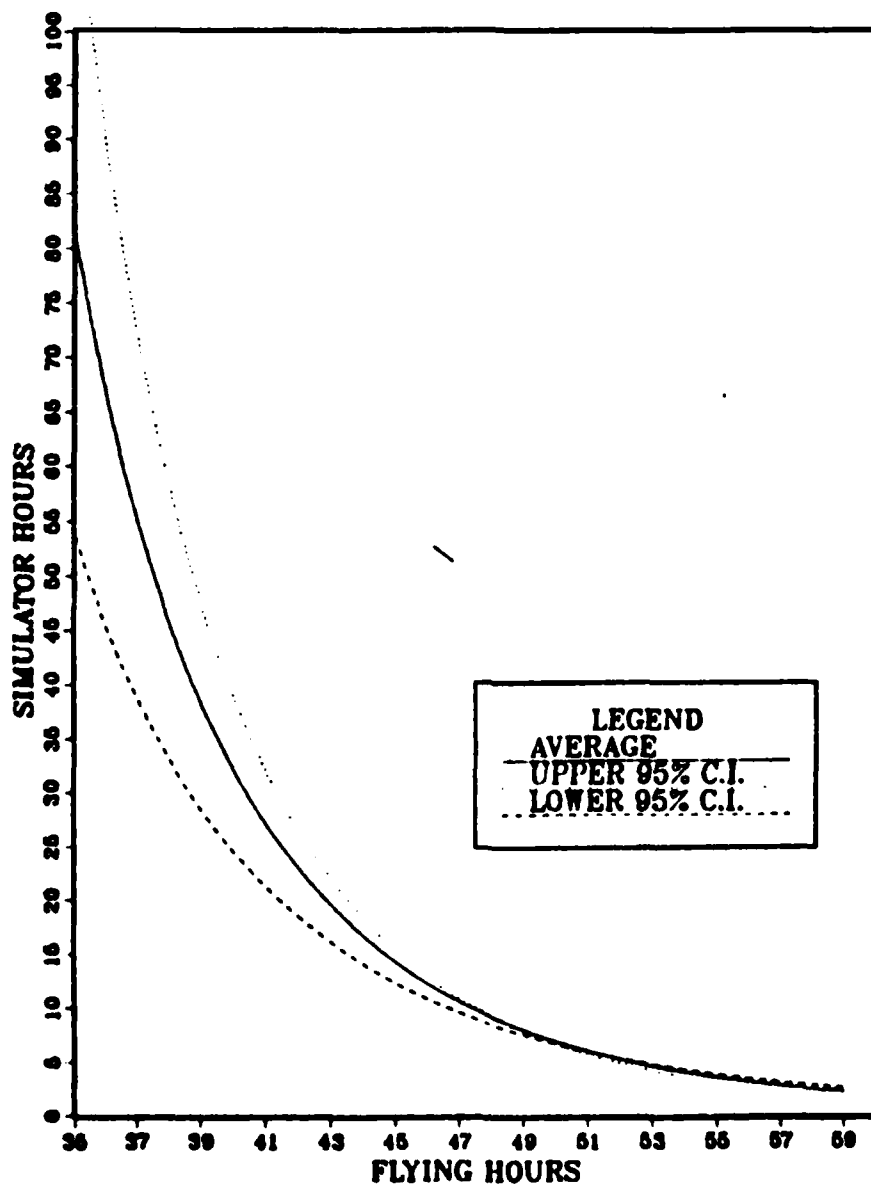
48

EFFECTIVENESS ISOQUANT – TRANS'

Figure IV - 5
The Effectiveness Isoquants - Transporters

$$SH = \text{antilog } 14.2 * FH^{-7.87}$$

$$R = 98.7\%$$

3. Effectiveness isoquant that is based on the lower 95% confidence interval Transfer Effectiveness ratio:

$$SH = \text{antilog } 10.7 * FH^{-5.81}$$

$$R^2 = 98.8\%$$

The upper 95% C.I. effectiveness isoquant is used in the rest of the analysis.

The following average costs are used in the submodel computations of the total cost of training:

(a) Constant average cost of a transport hour - $3140.

(b) Average cost of a flying hour with a learning curve of 90%.

(c) Constant average cost of a transport simulator hour = $550.

(d) Average cost of a transport simulator hour with a learning curve of 90%.

Fig. IV - 6 shows four different cost curves based on the above methods of computing average training hour cost and how they relate to the yearly flying hours that are implied by the effectiveness isoquant.

Point A on the graph represents the existing yearly cost of training a transport pilot:

$$C = 3140 * 50 + 550 * 6 = \$160,300$$

Table IV - 7 summarizes the differences between the existing training mix and four points of least cost training mixes (B-E).

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TRAINING COST – TRANSPORTERS

LEGEND
CONSTANT AVERAGE COST
DECREASING AVERAGE FH COST
DECREASING AVERAGE SH COST
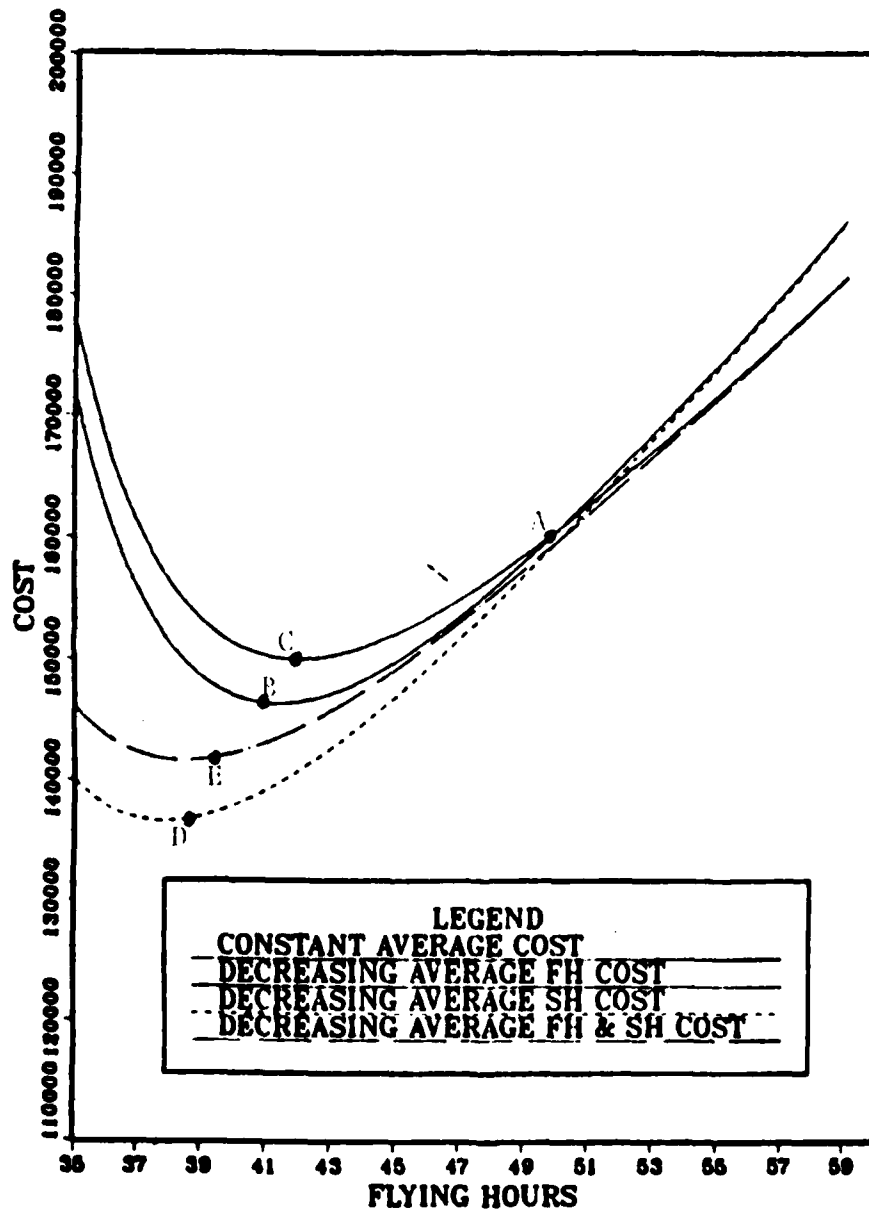DECREASING AVERAGE FH & SH COST

Figure IV - 6
The Training Cost Curves - Transporters

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TABLE IV -7

COST EFFECTIVENESS - PRESENT TRANSPORTER MIX

Point	Method of Computing Average Cost		Least Cost Mix		Cost of Training	Cost Effectiveness
	Flying Hour	Simulator Hour	Flying Hours	Simul. Hours		
B	constant	constant	41	32	$146,340	-$13,960
C	90% learning curve	constant	42	26	$149,722	-$10,578
D	constant	90% learning curve	39	48	$137,117	-$23,783
E	90% learning curve	90% learning curve	40	39	$142,224	-$18,076

The conclusion, at this stage of the analysis, is that without considering any constraints, the transport pilot training is not cost effective by the range of $10,578 - $23,183, which is 6.6% - 14.5% of the present cost of training.

Before concluding on the cost-effective mix and what can be really saved, two constraints will be introduced as an example:

(a) Total yearly simulator hours cannot exceed total yearly flying hours.

(b) Total increase in yearly training hours cannot exceed 50% of the present training hours.

Solving the problem of the least cost feasible training mix by linear programming techniques leads us to the conclusions that are summarized in Table IV - 8.

TABLE IV - 8

THE COST EFFECTIVE TRAINING MIX - TRANSPORTER PILOT

Method of Computing Average Cost		Least Cost Feasible Mix		Cost of Training	Saving	
Flying Hour	Simulator Hour	Flying Hours	Simulator Hours		$	%
constant	constant	41	32	$146,340	$13,960	8.7%
90% learning curve	constant	42	26	$149,722	$10,578	6.6%
constant	90% learning curve	41	32	$139,133	$21,167	13.2%
90% learning curve	90% learning curve	40	39	$142,224	$18,076	11.3%

According to the results shown in Table IV - 8, $10,578 $21,167, which is 6.6$-13.2% of the training cost, can be saved from the training cost of an individual transport pilot by changing the existing training mix of 50 flying hours and 6 simulator hours to a training mix of 40 - 42 flying hours and 26 - 39 simulator hours, depending on the method of computing the average training hour cost.

E. SUMMARY

Comparing the cost effectiveness results in the three groups leads to the following conclusions:

1. The jet group is the least cost effective group. Some $61,586 - $95,376, which is 7.2% - 11% of the present cost of training, can be saved from the cost of training an indi vidual jet pilot by changing the training mix from 100 flying hours and 7 simulator hours to 87 flying hours and 67 simulator hours.

   Even by introducing more conservative constraints of no more than 25% increase in total training hours, a saving potential of $46,197 - $80,732, which is 5.4% - 9.4% from the cost of an individual pilot training, still exists.

2. The transport group has the potential of saving $10,578 - $21,167, which is 6.6% - 13.2% of the yearly cost of training an individual pilot. That can be achieved by changing the present average mix of 50 flying hours and 6 simulator hours to a yearly training mix of 40 - 42 flying hours and 26 - 39 simulator hours.

3. The helicopter community is cost effective in the training mix. Only if a 90% learning curve can be introduced in the future, a saving of $9,993-$13,456, which is 5.3%-7.2% of the yearly training cost of an individual pilot can be achieved by introducing a new mix of training. In this case, the existing mix of 80 flying hours and 20 simulator hours has to be changed to 71-72 flying hours and 53-58 simulator hours.

In order to complete the comparison among the three groups, the potential dollar savings should be multiplied by the number of pilots in each group. Although the author is prevented from doing it in this unclassified paper, it is obvious that the order of the potential savings is not going to be changed, and the jet community has the greatest potential for cost savings.

V. CONCLUSIONS AND RECOMMENDATIONS

As mentioned in the first chapter, the goals of this thesis are two:

a. To construct a model that can be used to analyze the air crews training flying, and simulator hours cost effectiveness mix in the I.A.F.

b. To illustrate the use of the model, as an example in the Jet, Helicopter, and Transport communities in the I.A.F. The illustration was made by examining the following questions in each group:

(1) Is the existing mix of training cost effective?

(2) What is the potential cost-effective mix in each of the groups?

Along the way in developing the model, two important factors have been considered; the effectiveness of the training mix and the cost of training. The methods of measuring these two factors that are the foundation of the cost-effectiveness model are very weak and some ways to strengthen those methods were considered.

The existing ways of measuring air-crews training effectiveness are limited mainly to the peace-time environment and, as a result, to the technical skills of the pilot and not to his actual performance and quality as a fighter pilot. Hence, the pilots' knowledge and experience were chosen as a way to measure training effectiveness. They were asked to express their opinions on the various training combinations that have the potential of keeping the existing level of training effectiveness. It is recommended that this measuring tool be strengthened and updated by a long-term experiment with a small representative group of pilots.

The existing way of measuring an average cost of a flying

hour implies a constant average cost. It is obvious that, over

a wide range of flying hours, the average cost of a flying hours

is changed. In order to reduce the sensitivity of our model

to the change of the average cost of a flying hour, the learning

curve theory has been introduced and used in the examples.

It is recommended to develop a more realistic flying hour cost

estimation model, one that can strengthen this model and, probably,

can be used to update various other cost effectiveness models.

There is no model to compute the cost of simulator training

hours. The dollar values that were used in our model is based

on the cost of simulator training outside the country, which

are the only cost estimates that are in existence in the I.A.F.

As was demonstrated in the example analysis, and will be summarized

later, the average cost of a simulator hour is the most influential

factor in the model. It is recommended that a training simulator

hour cost estimation model be developed before going into a

training mix cost effectiveness analysis.

To illustrate the use of the model, three groups were

chosen - the Jets, Helicopters, and the Transports. For reasons

of classification, the illustration was limited to the average

pilot from each of the groups. The term "average pilot," in

this case, is a way of considering various levels of experience,

status, and type of aircraft as one level, a level that gets

constant yearly flying and simulator hours, and has a yearly

fixed cost. While doing the analysis this way may prevent us

from directly implementing the results, it does give us a clear

and general picture of the training cost effectiveness, differences
among the three groups, and the dominant factors in the analysis.

Table V - 1 summarizes the main results in the demonstrated
analysis.

TABLE V - 1

DEMONSTRATE TRAINING COST EFFECTIVENESS ANALYSIS - RESULTS

Group	Existing Training Mix		Existing Cost of Training A Pilot	Cost Effective Mix		Potential Cost	Potential Saving	
	Flying Hours	Simul. Hours		Flying Hours	Simul. Hours		$	%
Jets	100	6	$860,648	87	67	$765,272-$799,062	$61,586-$95,376	7.2-11.2
Heli-copters	80	20	$187,240	80-71	20-58	$187,240-$173,784	$0-$13,456	0%-7.2%
Trans-porters	50	6	$160,300	42-40	26-39	$149,722-$139,133	$10,578-$21,167	6.6%-13.2%

The jet group has the greater saving potential by introducing
a cost-effective training mix. the helicopter group training
mix can be considered as cost effective, and only by introducing
a 90% learning curve in the simulator training hour cost estimation
model, a saving of up to 7.2% can be achieved.

A potential saving of $10,578 - $21,167 of the existing
cost of training a pilot can a achieved in the transports group.

In the context of these results, the following remarks
have to be considered:

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(a) Multiply the cost saving by the numbers of pilots; this will not change the order of potential cost saving. On the contrary, the jet group will stay high in the list.

(b) Two conservative constraints have been used in the model:

  (1) Simulator hours cannot exceed flying hours.

  (2) Total training hours cannot exceed 50% of the existing total training hours.

(c) The cost of an average simulator hour is a very powerful factor in the model. This can be demonstrated by the following examples:

  (1) In the Jet group, the existing constant cost of a simulator hour is $566, which is 6.6% of the flying hour cost. Using the constant average cost model, 67 simulator hours, which is 11 times the existing simulator hours, have to be introduced in the cost effective model.

  (2) In the Transport group, the existing constant cost of a simulator hour is $550, which is 17.5% of the flying hour cost. Using the constant average cost model, 32 simulator hours, which is only 5.3 times the existing simulator hours, have to be introduced in the cost effective model.

  (3) In the Helicopter groups, the constant cost of a simulator hour is $562, which is 25% of the flying hour cost. Using the constant average cost model, the existing 20 yearly simulator hours are cost effective.

Although the relative cost of the simulator hour is not the only factor that influences the model results, it is obvious from the above examples that reducing the simulator hour cost has a great saving potential.

Finally, the results of the example analysis show a very large increase in simulator hours. Such an increase has various implications that were not examined in this paper, but should be examined when updating the model constraints.

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